OPTICAL TECHNOLOGY
APOLLO EXTENSION SYSTEM
PART I

EXECUTIVE
SUMMARY REPORT

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SPACE DIVISION CHRYSLER CORPORATION

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October 21, 1966

Approved by: William W. Kloepfer
William W. Kloepfer
Program Manager

CHRYSLER CORPORATION SPACE DIVISION, MICHOUD ASSEMBLY FACILITY
P.O. BOX 29200, NEW ORLEANS, LA. 70129

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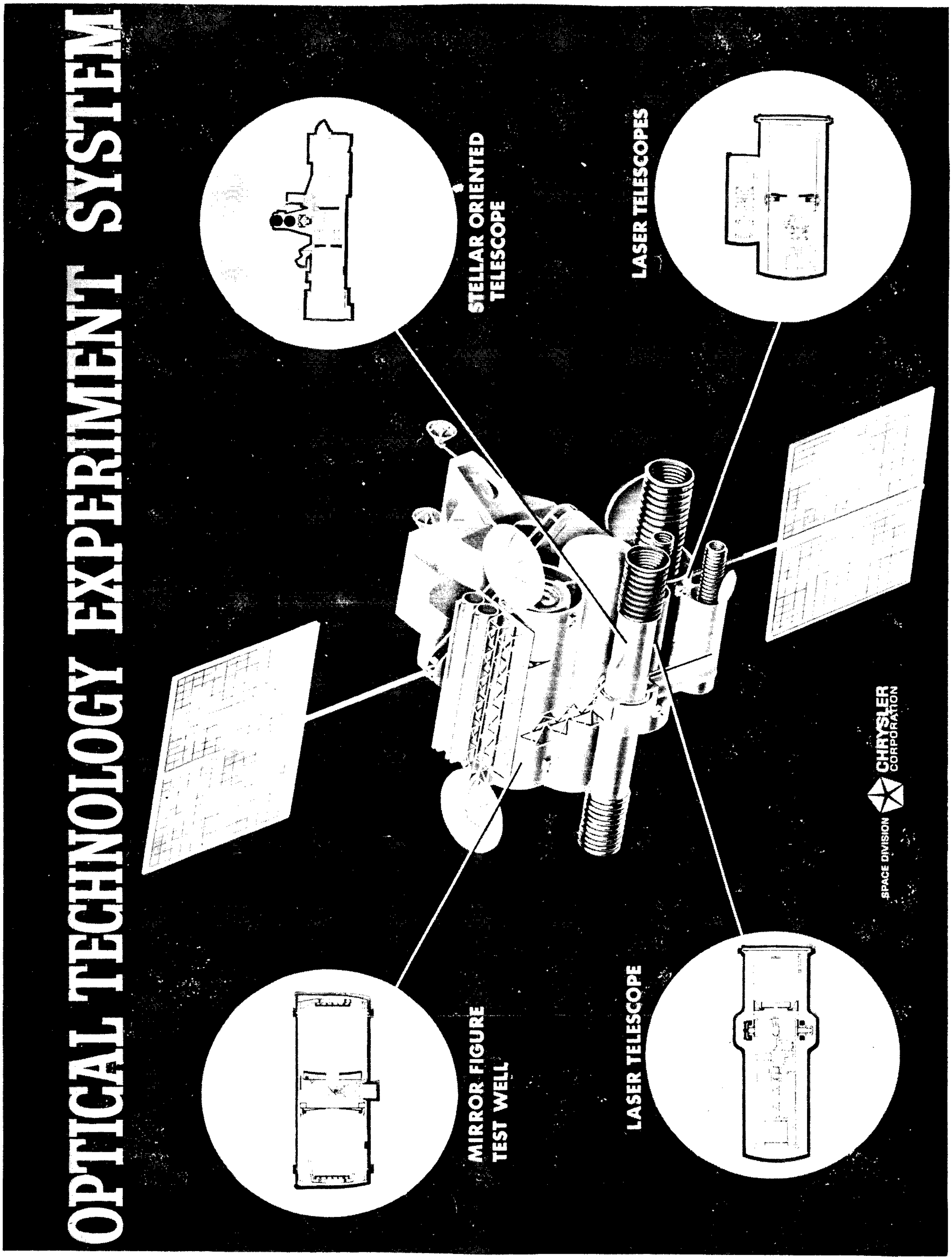
TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

PREFACE

The final report of the Optical Technology Apollo Extension System prepared for NASA/Marshall Space Flight Center under Contract Number NAS8-20256 is presented in three volumes. The study was a team effort by Chrysler Corporation Space Division (prime contractor), Kollsman Instrument Corporation, and Sylvania Electronics Systems.

The OTAES team gratefully acknowledges the help given by the NASA Ad Hoc working group during the course of this study.


OPTICAL TECHNOLOGY EXPERIMENT SYSTEM
STELLAR ORIENTED TELESCOPE
LASER TELESCOPES
MIRROR FIGURE TEST WELL
LASER TELESCOPE
SPACE DIVISION CHRYSLER CORPORATION

EXECUTIVE SUMMARY

THE OPTICAL TECHNOLOGY APOLLO EXTENSION SYSTEM

I. INTRODUCTION

The United States' lead in the space science applications of astronomy, meteorology, and planetology depends acutely on a continued advancement in the optical technologies. The scientific potential of optical instruments operating in space is evident throughout a whole spectrum of applications as in the areas of astronomy; earth remote sensing and resource conservation to better man's existence; weather prediction for his safety and convenience; and further manned exploration to extend his knowledge of the origin and nature of the Earth, the sun, the stars, and the universe. In addition to these applications, a means must be found to return this information to Earth at high data rates from long distances in space. All of these applications require advancements in optical technology which are beyond the current state-of-the-art.

Recognizing this technological gap, the National Aeronautics and Space Administration and more specifically the Office of Advanced Research and Technology has instituted numerous and varied optical programs seeking the needed advances. For maximum benefit, many of these programs will require space testing. The Optical Technology Apollo Extension System (OTAES), a program which unifies these multiple objectives through a sequence of laboratory, field, flight, and orbital tests, is described herein. The philosophy of this program circumvents the shortcomings and high risks involved when technology is advanced by brute force methods.

A set of spaceborne optical technology experiments and an associated sequence of supporting technology advances have been identified as essential and will advance the national optical capability. Alternative methods of providing NASA with planning flexibility for implementing this program are described, and the need for a unified, overall optical technology development and space test program is documented.

As this study progressed, it became clear that first considerations must be given to those technological developments which require space tests, since these will be the pacing items. It also became evident that an integrated, comprehensive development plan must be implemented which will detail both (1) those advances which require space testing and (2) those which can be accomplished on Earth. But perhaps the most significant revelation of this study is the time scale of a thorough, scientific tempo of development. The program of optical technology development which we have recommended – and which we believe to be sensibly minimal in scope – will require up to 7 years.

An urgency is evident which would best be served by prompt recognition of the need for an OTAES Flight Program.

II. PROGRAM PHILOSOPHY

During the course of these initial conceptual and feasibility studies, it became increasingly clear that identification in detail of an integrated development plan for space optics technology would be extremely fruitful. In developing this plan to maintain this nation's lead in space, first consideration was given to those technological developments which require space tests, as these, along with the necessary prerequisite ground test, will be the long lead time elements of the development program. See figure 1. Consequently, the first logical step in the development of the overall plan is to isolate those requirements which need space tests and prepare an experimental test program to satisfy these requirements. The results are highly revealing.

1) Optical technology must now be developed in a more organized and logical manner.

2) A number of feasible experiments can be implemented which will provide required technological advance toward national space goals.

3) Because of its logical flow structure, it imposes an economic discipline upon itself.

4) Because it is organized and well-planned, it offers assurance of application reliability.

5) Because there are time constraints on attaining scientific knowledge, this technology must be advanced now.

With this underlying philosophy, the OTAES studies have proceeded to: (a) reduce to quantitative form those space scientific objectives which require optical technology such as astronomy, meteorology, earth remote sensing, and interplanetary missions; (b) state the technology requirements for these objectives; (c) identify alternate solutions to these problem areas; (d) formulate space experiments to achieve the above objectives; (e) define the key ground development programs needed to support such experiments; (f) conceptually integrate these experiments into space packages under realistic spacecraft and mission requirements; and (g) describe an overall technology plan showing development milestones in the earth-based program, schedules for each individual experiment, and master plan alternatives for the overall experiment program to achieve the technology objectives.

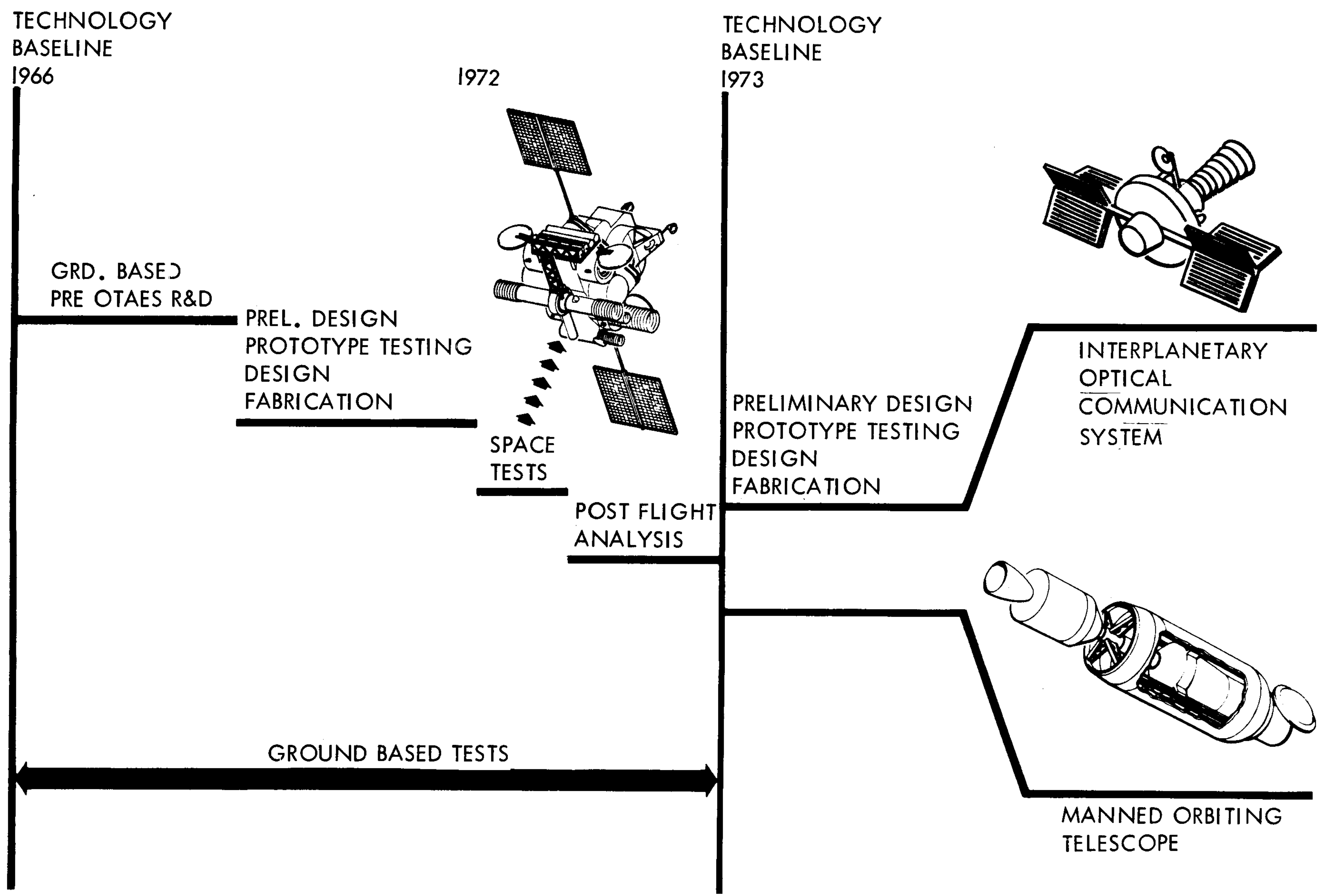


Figure 1. Space Optical Technology Development

III. CONCLUSIONS

The major conclusions of Part I of OTAES study are presented for convenience in six categories. These conclusions form the basis for the recommendations appearing in the next section.

1. Commonality

There is a broad commonality of the optical technology needed for astronomy, for remote sensing of the Earth, for meteorology, for planetary observation, and for space optical communications. That is, there is a commonality of application. See figure 2.

If the special scientific and government groups associated with each of these applications were to develop the technology required for their particular interest, the resulting programs would overlap and no one of them could be as effective in providing timely, reliable, and economic space optical technology, and NASA would find itself paying twice for its technology. Moreover, there are optical instruments which would be desirable to more than one of these special interests but whose development can be more fully justified because of the multiple applications. Consideration of the technology from the standpoint of its application, therefore, in two ways forcefully compels the conclusion that a single technology development program must be instituted and sustained.

There is also a commonality of development programs. For the optical technology which requires space testing for its development, significant advantages are gained by flying the experiments in groups even though each of them could be flown singly. For instance, the nine propagation experiments require identically the same equipment for their performance.

In summary then,

- The needed optical technology is common to all of the potential applications.
- The needed optical technology leads to common development experiments and programs.
- This commonality strongly favors a comprehensive integrated development program.

2. Completeness

The OTAES contract is limited to consideration of the technology which leads to space testing. Increased emphasis by NASA is needed to develop an orderly program for advancing the optical technology not covered by the present OTAES contract. A better statement of this conclusion is that a comprehensive, orderly program for optical technology should include in proper perspective both that part which leads to space testing and that part which does not.

		TECHNOLOGY	SPACE ASTRONOMY							INTERPLANETARY						METEOROLOGY						EARTH REMOTE SENSING		
		APPLICATIONS	HIGH RESOLUTION	SPECTROSCOPY	PHOTOMETRY	INTERFEROMETRY	WIDE ANGLE SURVEYS	SOLAR OBSERVATIONS	ASTRONOMETRIC	COMMUNICATIONS	MAPPING	HIGH RESOLUTION IMAGE	SURFACE CONTOUR	ATMOSPHERIC PROPERTIES	TEMPERATURE MAPPING	HIGH RESOLUTION IMAGERY	DISTRIBUTION OF CONSTITUENTS	CLOUD TOP & AEROSOL ALTITUDE	VERTICAL TEMPERATURE PROFILE	POINT-TO-POINT TURBULENCE	POINT-TO-POINT SCATTERING	HIGH RESOLUTION IMAGERY	CONTOUR MAPPING	THERMAL MAPPING
SPACE TELESCOPE TECHNOLOGY	1	MIRROR SURFACE DEGRADATION	△	△	△		△	△		●	●	△	●	●	△	△	△	●	△	●	●	△	●	●
	2	MIRROR FIGURE CONTROL	△	●	●	●	●	●	●	△		△	●	●	●	△	●	●	●	●	●	△	●	●
	3	ALIGNMENT & FOCUSING	△	△	●	△	●	△	●	△	●	△	●	●	△	△	△	●	△	●	●	△	●	●
	4	THERMAL COMPENSATION	△	△	●	△	●	●	●	△	●	△	●	●		△	●	●		●		△	●	●
	5	BEAM STABILITY	△	△	●	△	●	●	●	●		△		●		△						△	●	●
	6	PRECISION DEPLOYMENT	△			△		△				△				△						△		
	7	BAFFLES	●	●	●	●	●	△	●	●	●	●				△						△		
	8	LAUNCH ISOLATION	△	△	●	△	●	△	●	△		△			●	△	△	●	●	●	●	△		
	9	SMALL DISPLACEMENT ACTUATORS	△	△	△	△	●	△	△	△		△				△						△		
CONTROL & STABILIZATION	10	FINE ERROR SENSORS	△	△	△	●		●		△		△		△		△						△	△	△
	11	FINE BEAM DEFLECTORS	△	△	△	●		●		△		△				△						△		
	12	ISOLATION TECHNIQUES	△	△	●	●	●	△	△			△				△						△		
	13	ACQUISITION	△	△	△	△	△	△	△	△		△		●	△	△	△	△	△	△	△	△	△	●
	14	IMAGE MOTION COMPENSATION									△	△	△		●	△	△	△	△			△		
DETECTORS	15	HIGH RESOLUTION IMAGE TUBES	△	△		●		△			●	△				△						△		
	16	LOW LEVEL IMAGE TUBES	△	△	△		△				△	△												
	17	BROADBAND PHOTOELECTRIC DET.			△										●									●
	18	LARGE AREA PHOTO CATHODES	△									△				△						△		
	19	FAR INFRARED DETECTORS		△	△		△	△						△		△	△		△			△	△	△
	20	DRY EMULSIONS	△	△	△	△	△	△	△			△				△	●	●				△	△	
	21	HIGH DATA CAPACITY PHOTOGRAPHIC RECORDING	△	●			△	●			△	△												
	22	XUV SENSITIVE PHOTO EMULSIONS	△	△			△	●				△		●			●					△	△	●
	23	MECHANICAL IMAGE SCANNING												△		△						△	△	△
LASERS	24	DIRECT DETECTION								△		△	△		△			△		△	△		△	
	25	HETERODYNE DETECTION								△		△			△			△		△	△			
	26	ATMOSPHERIC TRANSFER FUNCTION								△		△	△		△		●	●	●	△	△		△	
	27	SCATTERING & ABSORPTION											△		△			△		△	△		△	
	28	RANGE RATES											△										△	
AUXILIARY DEVICES	29	DISSECTOR		△																				
	30	OBJECTIVE GRATING MOSAIC					△																	
	31	MICHELSON INTERFEROMETER				△			●															
	32	FABRY PEROT INTERFEROMETER				△			●															
	33	PHOSPHOR CAMERA					△																	
	34	UV CORONOGRAPHY						△																
	35	SLIT SPECTROGRAPH		△				△																

▭ WEAK RELATIONSHIP ● SIGNIFICANT RELATIONSHIP △ MAJOR REQUIREMENT

Figure 2. Commonality of Technology Matrix

The ultimate responsibility for this planning, of course, rests with NASA, but the needed program should so intertwine with the OTAES program as to necessitate the participation by the OTAES contractor in the technology planning.

A fuller treatment of technology now excluded from OTAES study by contractor specialists should be defined so as to take advantage of the potential experiments which do not qualify for space testing but are nevertheless important elements of a comprehensive program.

3. Experiment Program

The OTAES has identified 15 experiments which are recommended for flight. Illustrative experiment concepts have been synthesized for the purpose of establishing individual experiment feasibility, compatibility within logical groupings of related experiments, and practicality within the context of supporting technologies. In essence, these studies have bounded the problem. The results show that an OTAES would make a significant and needed contribution to the national space program, that OTAES is technologically and economically feasible, and that the OTAES mission concept imposes no extraordinary support requirements. These conceptual studies have identified critical development areas and test programs which must precede the construction and launch of an orbiting optical technology experiment system. However, it cannot be said that these experiments and the OTAES alternative missions are truly designed. The effort has only been carried to a point sufficient to assure the feasibility and practicality of an OTAES development program and to be certain that such a program would be a significant contribution to the national space goals.

The recommended experiments are:

1. Optical Heterodyne Detection on Earth.
2. Optical Heterodyne Detection on the Spacecraft.
3. Direct Detection Space-to-Ground.
4. Communication with 10 Megahertz Bandwidth.
5. Precision Tracking of a Ground Beacon.
6. Point Ahead and Space-to-Ground-to-Space Loop Closure.
7. Transfer Tracking from One Ground Station to Another.
8. Phase Correlation Measurements.
9. Pulse Distortion Measurements.
10. Primary Mirror Figure Test and Correction.
11. Thin Mirror Nesting Principle and Erection and Alignment of Large Optics in Space.
12. Fine Guidance.
13. Comparison of Isolation Techniques.

14. Interferometer Systems.

15. Segmented Optics.

4. Missions

Nine different missions involving four different launch vehicles were evaluated from the standpoint of performing the recommended OTAES experiments. Four of these were selected as candidate missions. Furthermore, it was concluded that all of the experiments recommended in this study could be performed on a synchronous manned mission. Alternatively, all experiments except one, Interferometer Development, could be performed on a combination low earth orbit manned mission and a synchronous unmanned mission. Within certain constraints a synchronous orbit coupled with the judicious choice of ground station configuration permits all of the experiments to be performed on a single ground station complex including terminals for point ahead and tracking transfer experiments.

A preliminary time line analysis indicated that the manned portion of a synchronous mission could be accomplished in 15.5 days. During this period all recommended experiments could be performed at least once.

In summary,

- There are several alternatives for performing the recommended experiments, and
- None of the alternatives require major spacecraft or space vehicle development, and
- One ground station complex link is sufficient.

5. Spaceborne Support

An evaluation of the required spacecraft support indicated that all experiments could be performed with modified Apollo hardware characteristic of AAP missions. Although more than 20 configurations were considered, it was concluded that the performance of OTAES experiments would not require a major spacecraft development program. Apollo modifications planned for other missions would satisfy most OTAES requirements.

Similarly, spacecraft subsystem requirements could be satisfied with either existing or planned technology. For instance, for a mission in which all experiments are performed on one flight, the preferred power system would use oriented solar panels to augment the existing Apollo systems. Furthermore, the spacecraft attitide stability should be provided by control moment gyros with reaction jets used for periodic dumping of accumulated angular momentum. Although the control moment gyros would represent a modification to Apollo spacecraft, this specific technology is advancing rapidly independent of the OTAES program and, in fact, might well be adapted to the LEM Ascent Stage for such programs as the Apollo Telescope Mount.

In súmmary,

- All flight experiments can be performed with modified Apollo hardware without a major spacecraft development program, and
- Subsystem technologies are adequate to support the experiments.

6. OTAES Schedules

Given a pre-OTAES research and development program as identified in the OTAES study, the maximum required time to the first OTAES launch capability is approximately seven years. The pre-OTAES research and evelopment program would require a maximum of three years prior to OTAES preliminary design. There is very small variation in experiment availability, which reflects into a small schedule variation for each of the missions. Figures 3 and 4 give the experiment availability for 16 recommended experiments. Figure 5 shows the flight data for the four recommended missions. The pacing item in experiment availability is the telescope development design and fabrication.

In summary,

- The schedules for flight experiments call for lead times that are long enough to impart some urgency to getting started now.

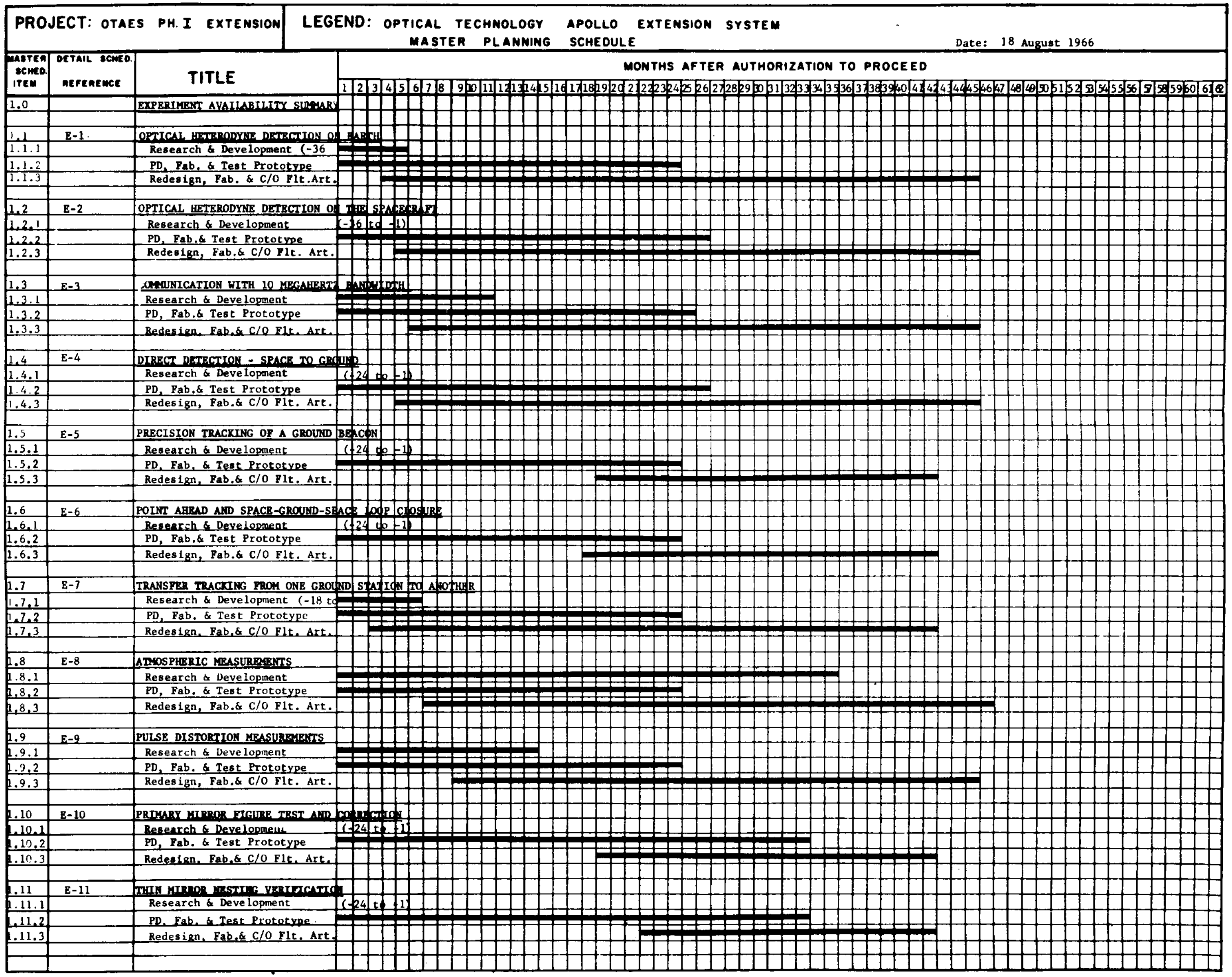

PROJECT: OTAES PH. I EXTENSION
LEGEND: OPTICAL TECHNOLOGY APOLLO EXTENSION SYSTEM
MASTER PLANNING SCHEDULE
Date: 18 August 1966
MASTER SCHED. ITEM
DETAIL SCHED. REFERENCE
TITLE
MONTHS AFTER AUTHORIZATION TO PROCEED
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62
1.0 EXPERIMENT AVAILABILITY SUMMARY
1.1 E-1 OPTICAL HETERODYNE DETECTION ON EARTH
1.1.1 Research & Development (-36
1.1.2 PD, Fab. & Test Prototype
1.1.3 Redesign, Fab. & C/O Flt.Art.
1.2 E-2 OPTICAL HETERODYNE DETECTION ON THE SPACECRAFT
1.2.1 Research & Development (-36 to -1)
1.2.2 PD, Fab.& Test Prototype
1.2.3 Redesign, Fab.& C/O Flt. Art.
1.3 E-3 COMMUNICATION WITH 10 MEGAHERTZ BANDWIDTH
1.3.1 Research & Development
1.3.2 PD, Fab.& Test Prototype
1.3.3 Redesign, Fab.& C/O Flt. Art.
1.4 E-4 DIRECT DETECTION - SPACE TO GROUND
1.4.1 Research & Development (-24 to -1)
1.4.2 PD, Fab.& Test Prototype
1.4.3 Redesign, Fab.& C/O Flt. Art.
1.5 E-5 PRECISION TRACKING OF A GROUND BEACON
1.5.1 Research & Development (-24 to -1)
1.5.2 PD, Fab. & Test Prototype
1.5.3 Redesign, Fab.& C/O Flt. Art.
1.6 E-6 POINT AHEAD AND SPACE-GROUND-SPACE LOOP CLOSURE
1.6.1 Research & Development (-24 to -1)
1.6.2 PD, Fab.& Test Prototype
1.6.3 Redesign, Fab.& C/O Flt. Art.
1.7 E-7 TRANSFER TRACKING FROM ONE GROUND STATION TO ANOTHER
1.7.1 Research & Development (-18 to
1.7.2 PD, Fab. & Test Prototype
1.7.3 Redesign, Fab.& C/O Flt. Art.
1.8 E-8 ATMOSPHERIC MEASUREMENTS
1.8.1 Research & Development
1.8.2 PD, Fab. & Test Prototype
1.8.3 Redesign, Fab.& C/O Flt. Art.
1.9 E-9 PULSE DISTORTION MEASUREMENTS
1.9.1 Research & Development
1.9.2 PD, Fab. & Test Prototype
1.9.3 Redesign, Fab.& C/O Flt. Art.
1.10 E-10 PRIMARY MIRROR FIGURE TEST AND CORRECTION
1.10.1 Research & Development (-24 to -1)
1.10.2 PD, Fab. & Test Prototype
1.10.3 Redesign, Fab.& C/O Flt. Art.
1.11 E-11 THIN MIRROR NESTING VERIFICATION
1.11.1 Research & Development (-24 to -1)
1.11.2 PD, Fab. & Test Prototype
1.11.3 Redesign, Fab.& C/O Flt. Art.

Figure 3

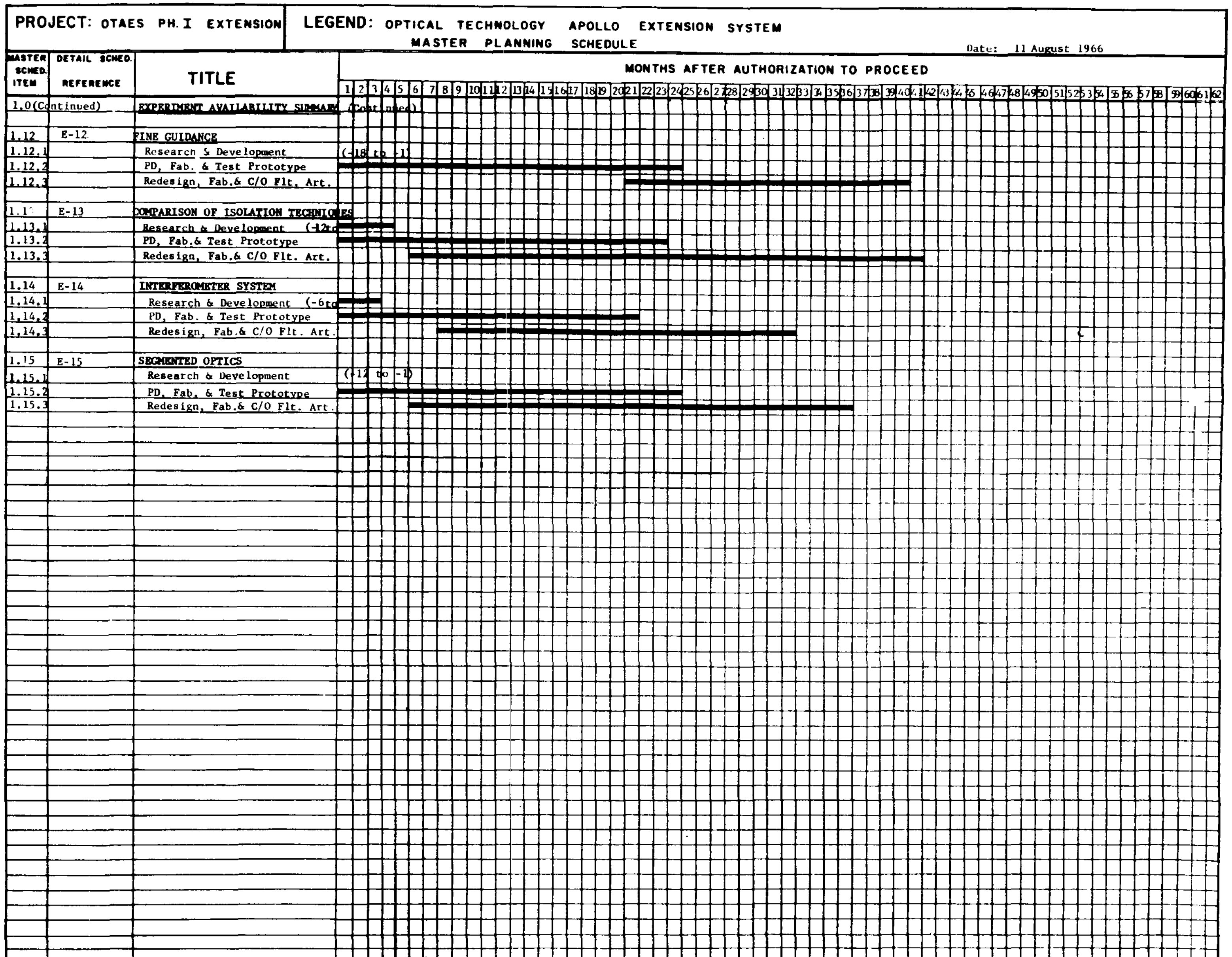

PROJECT: OTAES PH. I EXTENSION
LEGEND: OPTICAL TECHNOLOGY APOLLO EXTENSION SYSTEM
MASTER PLANNING SCHEDULE
Date: 11 August 1966
MASTER SCHED. ITEM
DETAIL SCHED. REFERENCE
TITLE
MONTHS AFTER AUTHORIZATION TO PROCEED
1.0(Continued)
EXPERIMENT AVAILABILITY SUMMARY (Continued)
1.12 E-12 FINE GUIDANCE
1.12.1 Research & Development (-18 to -1)
1.12.2 PD, Fab. & Test Prototype
1.12.3 Redesign, Fab.& C/O Flt. Art.
E-13 COMPARISON OF ISOLATION TECHNIQUES
1.13.1 Research & Development
1.13.2 PD, Fab.& Test Prototype
1.13.3 Redesign, Fab.& C/O Flt. Art.
1.14 E-14 INTERFEROMETER SYSTEM
1.14.1 Research & Development
1.14.2 PD, Fab. & Test Prototype
1.14.3 Redesign, Fab.& C/O Flt. Art.
1.15 E-15 SEGMENTED OPTICS
1.15.1 Research & Development (-12 to -1)
1.15.2 PD, Fab. & Test Prototype
1.15.3 Redesign, Fab.& C/O Flt. Art.

Figure 4

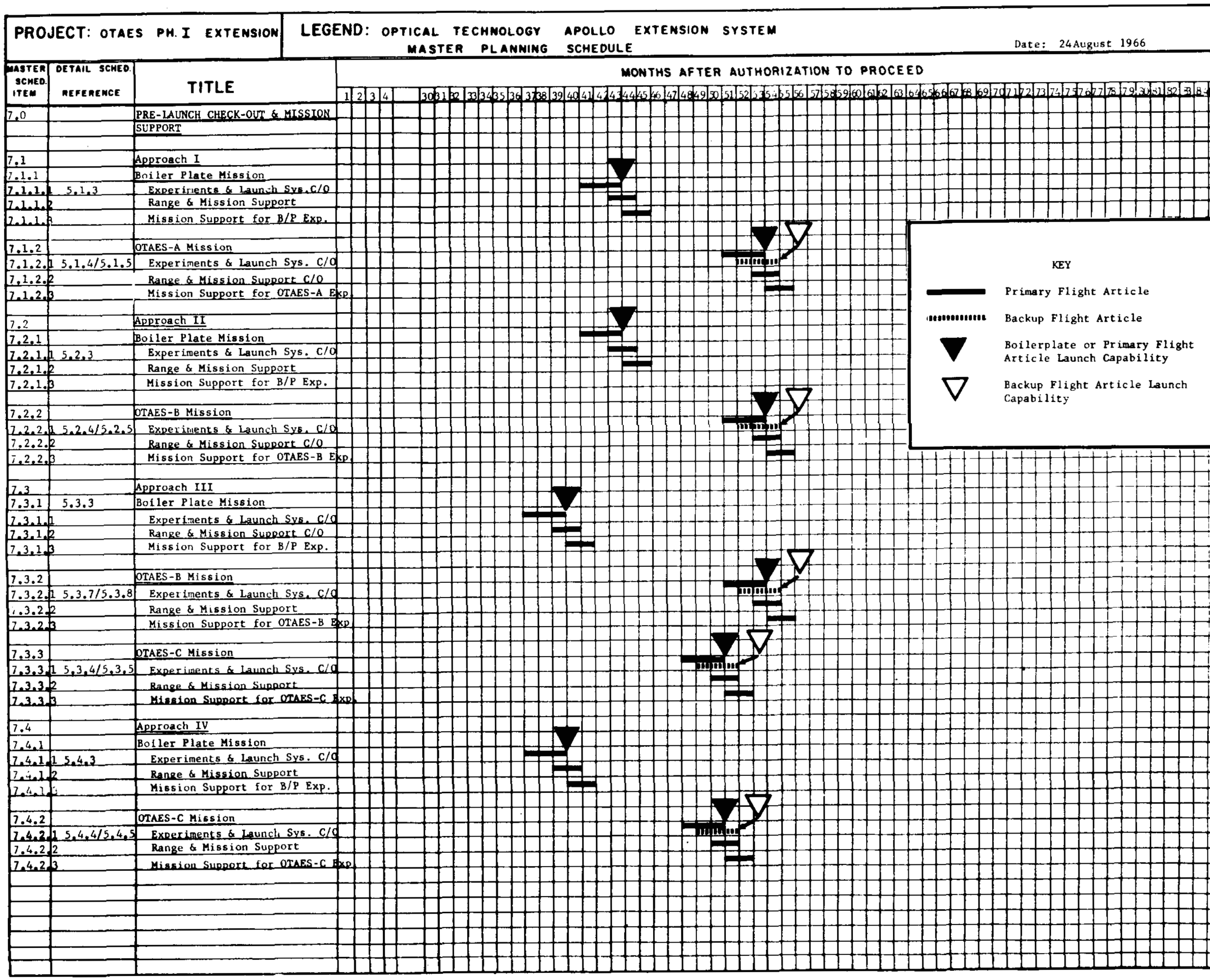

PROJECT: OTAES PH. I EXTENSION
LEGEND: OPTICAL TECHNOLOGY APOLLO EXTENSION SYSTEM
MASTER PLANNING SCHEDULE
Date: 24August 1966
MASTER SCHED. ITEM
DETAIL SCHED. REFERENCE
TITLE
MONTHS AFTER AUTHORIZATION TO PROCEED
7.0 PRE-LAUNCH CHECK-OUT & MISSION SUPPORT
7.1 Approach I
7.1.1 Boiler Plate Mission
7.1.1.1 5.1.3 Experiments & Launch Sys. C/O
7.1.1.2 Range & Mission Support
7.1.1.3 Mission Support for B/P Exp.
7.1.2 OTAES-A Mission
7.1.2.1 5.1.4/5.1.5 Experiments & Launch Sys. C/O
7.1.2.2 Range & Mission Support C/O
7.1.2.3 Mission Support for OTAES-A Exp
7.2 Approach II
7.2.1 Boiler Plate Mission
7.2.1.1 5.2.3 Experiments & Launch Sys. C/O
7.2.1.2 Range & Mission Support
7.2.1.3 Mission Support for B/P Exp.
7.2.2 OTAES-B Mission
7.2.2.1 5.2.4/5.2.5 Experiments & Launch Sys. C/O
7.2.2.2 Range & Mission Support C/O
7.2.2.3 Mission Support for OTAES-B Exp
7.3 Approach III
7.3.1 5.3.3 Boiler Plate Mission
7.3.1.1 Experiments & Launch Sys. C/O
7.3.1.2 Range & Mission Support C/O
7.3.1.3 Mission Support for B/P Exp.
7.3.2 OTAES-B Mission
7.3.2.1 5.3.7/5.3.8 Experiments & Launch Sys. C/O
7.3.2.2 Range & Mission Support
7.3.2.3 Mission Support for OTAES-B Exp
7.3.3 OTAES-C Mission
7.3.3.1 5.3.4/5.3.5 Experiments & Launch Sys. C/O
7.3.3.2 Range & Mission Support
7.3.3.3 Mission Support for OTAES-C Exp
7.4 Approach IV
7.4.1 Boiler Plate Mission
7.4.1.1 5.4.3 Experiments & Launch Sys. C/O
7.4.1.2 Range & Mission Support
7.4.1.3 Mission Support for B/P Exp.
7.4.2 OTAES-C Mission
7.4.2.1 5.4.4/5.4.5 Experiments & Launch Sys. C/O
7.4.2.2 Range & Mission Support
7.4.2.3 Mission Support for OTAES-C Exp
KEY
Primary Flight Article
Backup Flight Article
Boilerplate or Primary Flight Article Launch Capability
Backup Flight Article Launch Capability

Figure 5

IV. RECOMMENDATIONS

As a result of the OTAES Phase I study, a number of recommendations have been prepared. These recommendations are presented by categories.

General Optical Technology

1. Defintion of the projected optical technology needs in each of the application areas of astronomy, earth remote sensing, meteorology, and optical communications should be continued.

2. A study should be initiated to identify those technologies not in specific support of flight experiments. This will complement the optical technology associated with the OTAES experiments.

3. An overall optical technology program plan should be developed to relate these two programs and others which will have impact.

OTAES Flight Program

A. Experiments

4. It is recommended that 15 space experiments be flown. These are:

   a. Optical Heterodyne Detection on Earth.

   b. Optical Heterodyne Detection on the Spacecraft.

   c. Direct Detection Space-to-Ground.

   d. Communication with 10 Megahertz Bandwidth.

   e. Precision Tracking of a Ground Beacon.

   f. Transfer Tracking from One Ground Station to Another.

   g. Point Ahead and Space-to-Ground-to-Space Loop Closure.

   h. Phase Correlation Measurements.

   i. Pulse Distortion Measurements.

   j. Primary Mirror Figure Test and Correction.

   k. Thin Mirror Nesting Principle and Erection and Alignment of Large Optics in Space.

   l. Fine Guidance.

   m. Comparison of Isolation Techniques.

   n. Interferometer System.

   o. Segemented Optics.

5. A continued effort in defining new OTAES experiments should be maintained.

6. In particular, detector technology requires further investigation as an area in which fruitful space experiments might evolve.

7. The development of experiment justification should be continued and further supported by the new analyses recommended as necessary in the continuation of OTAES work.

B. Spacecraft and Missions

8. Four candidate spacecraft are recommended for further study to identify the configuration which most nearly meets all of the requirements. These are:

   a. Modified Apollo synchronous spacecraft.

   b. Synchronous spacecraft.

   c. Dual mission spacecraft.

   d. Near earth orbit LEM spacecraft.

9. A detailed study of the use of the Apollo spacecraft on a manned synchronous mission should be undertaken.

10. The feasibility of implementing some of the recommended experiments should be explored in greater detail. For instance, a control and stabilization simulation, a dynamic analysis, and a thermal analysis should be performed on the integrated configurations developed in this part of the OTAES study.

11. Four candidate missions are recommended for the OTAES program. These are:

   a. Manned synchronous misssion.

   b. Unmanned synchronous mission.

   c. Manned low earth orbit mission.

   d. Single-launch, dual-mission combining the unmanned synchronous and manned low earth orbit missions.

12. These mission and spacecraft candidates should be investigated for the purpose of determining an optimum OTAES flight program.

C. Operations Analysis

13. Further definition of OTAES support requirements such as the ground station, data handling, etc. is needed.

14. Further definition of the man/experiment interface is necessary to coincide with the level of experiment conceptual detail and the integrated experiment groupings developed in Part I.

15. Although the experiment concepts described in the report are feasible, they are not necessarily optimum. In particular, a consideration of alternatives which would enhance the overall OTAES probability of success (insure maximum technological data) is needed. A series of conditional probability analyses are needed which, when assembled, will relate success in all flight phases (launch, injection, experiment, etc.) with mission, spacecraft, and experiment grouping alternatives.

16. Specific elements of the above generated reliability estimates should be compared to reliability estimates for accomplishing the technological experiment objective directly in the application without the intermediate step. Such a comparison would yield a quantification of the OTAES technological gain.

17. It is recommended that the high reliability standards of the manned space program be maintained in all the space areas through the development of optimum technology to insure maximum national support of these future potential space goals.

18. Further analysis of the space operational environment for individual experiments is required. In particular, the contaminant environment and the influence of contaminant particle size and distribution on mirror degradation characteristics should be determined.

D. Planning

19. An OTAES technical plan should be developed which will describe the tasks required in the following OTAES phase and a plan for accomplishing these tasks.

20. An OTAES preliminary facility plan should be developed which defines the nature and extent of the facilities required for the OTAES flight program.

21. An OTAES preliminary test plan should be developed which indicates the nature and extent of test and checkout activity for the OTAES flight program.

22. An OTAES preliminary schedule should be prepared which will establish a feasible timing for development of the OTAES flight program and will identify the critical paths in this development and the urgency of timing of the specific development tasks.

23. An OTAES preliminary cost plan should be developed which will indicate the cost of the OTAES alternatives.

V. RECOMMENDED OTAES EXPERIMENTS

The experiments developed in the course of these studies have been categorized into three groupings for the purpose of generalized description.

Optical Propagation Group

The atmosphere has been studied for centuries from earth-bound observatories using the noncoherent light from stars. Rockets and satellites now permit remote measurements of the Earth and its atmosphere. Over the past decade, the national space program has accumulated many such data; and a large portion of these data were measured in the ultraviolet, visible, and infrared. To make optimum use of remotely sensed data, more must be known about the physics of the atmosphere and the effect of the atmosphere on optical signals passing through it. As a tool to advance our knowledge in these areas the laser possesses two highly useful properties: spatial coherence and temporal coherence. A laser transmitter can emit an extremely narrow, intense beam of monochromatic light. Furthermore, since they operate at frequencies sensitive to atmospheric absorption and scattering and variations in the index of refraction, the laser is the most promising instrument for obtaining a better understanding of the turbulent structure of the atmosphere.

To study the physics of the atmosphere using a spaceborne light source is to study the character of a space-ground transmission path. The establishment of such a path is tantamount to establishing an optical communication link. Indeed, the most promising operational application for lasers is wideband communication over extremely long distances. But, to achieve this goal, a foundation of spaceborne optical communication engineering data must be obtained. The propagation experiments, singly and as a group, are advanced as a means for studying the Earth's atmosphere as a prerequisite to the development of alternatives in the field of communication.

The optical propagation group is comprised of nine experiments. This group is pictorially represented in figure 6. The conceptual details of the spaceborne telescopes are shown in figures 7 and 8. Four of the experiments are directly associated with optical communications. Collectively, the space-to-ground communication experiments provide a comparison of the fundamental communication techniques: direct detection and heterodyne detection. Also, the heterodyne experiment, which is performed both in space and on the ground, is formulated on a scale sufficient to allow comparison between laser and radio frequency communication. Direct detection, which has the advantages of system simplicity, lenient pointing tolerances, and an advanced state of ground based development, is also the subject of a proposed experiment. Intimately related to the detection experiments, but operationally distinct, is the 10 megahertz bandwidth communication experiment in which the objective is to actually compare the wideband optical communication alternatives.

Three experiments of the optical propagation group are concerned with the development of the technology required for eventual optical communication from deep space. To utilize the narrow beams in which the laser power may be concentrated requires

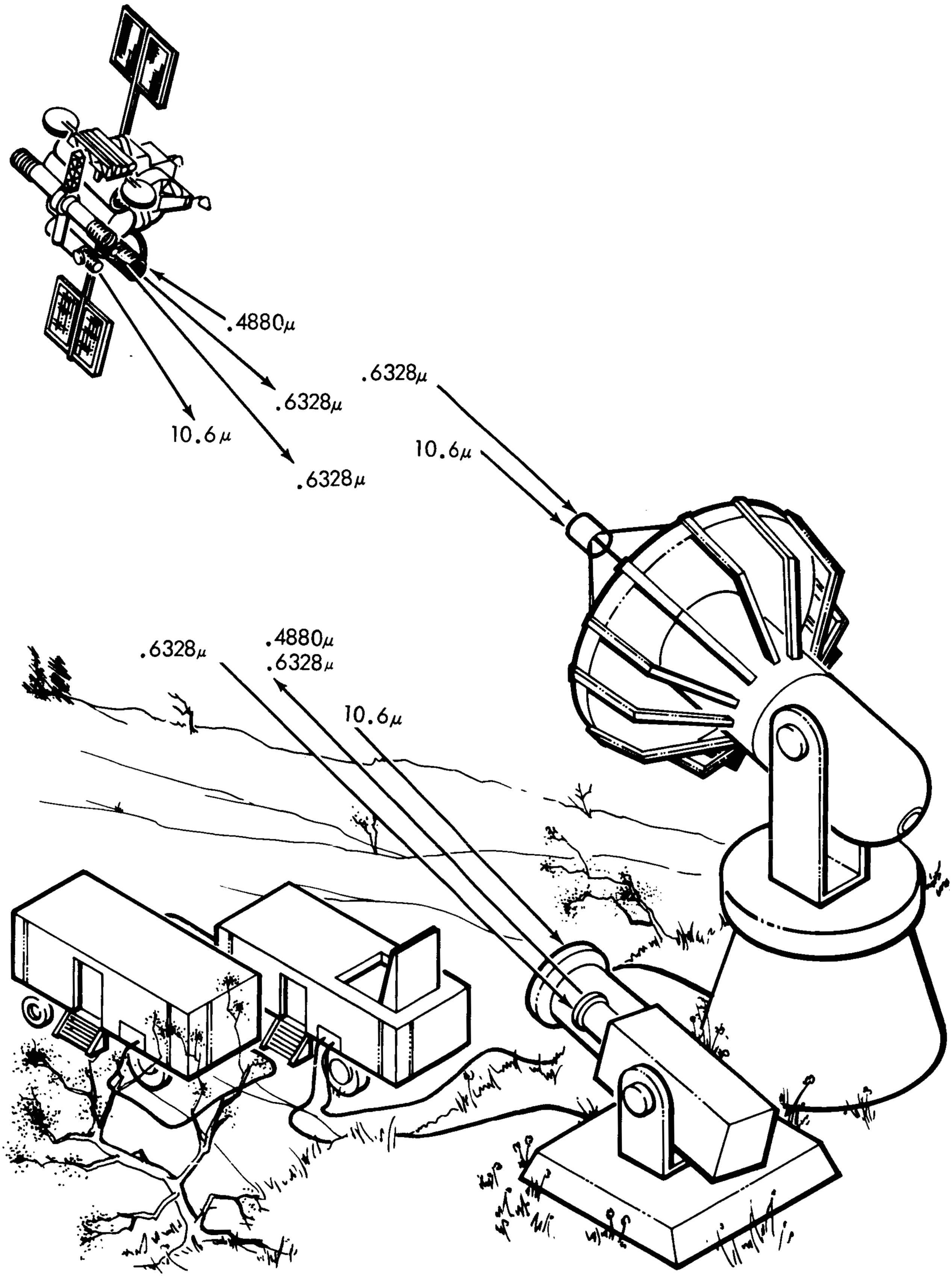


Figure 6. Spaceborne and Ground Equipment Concept for the Optical Propagation Experiment

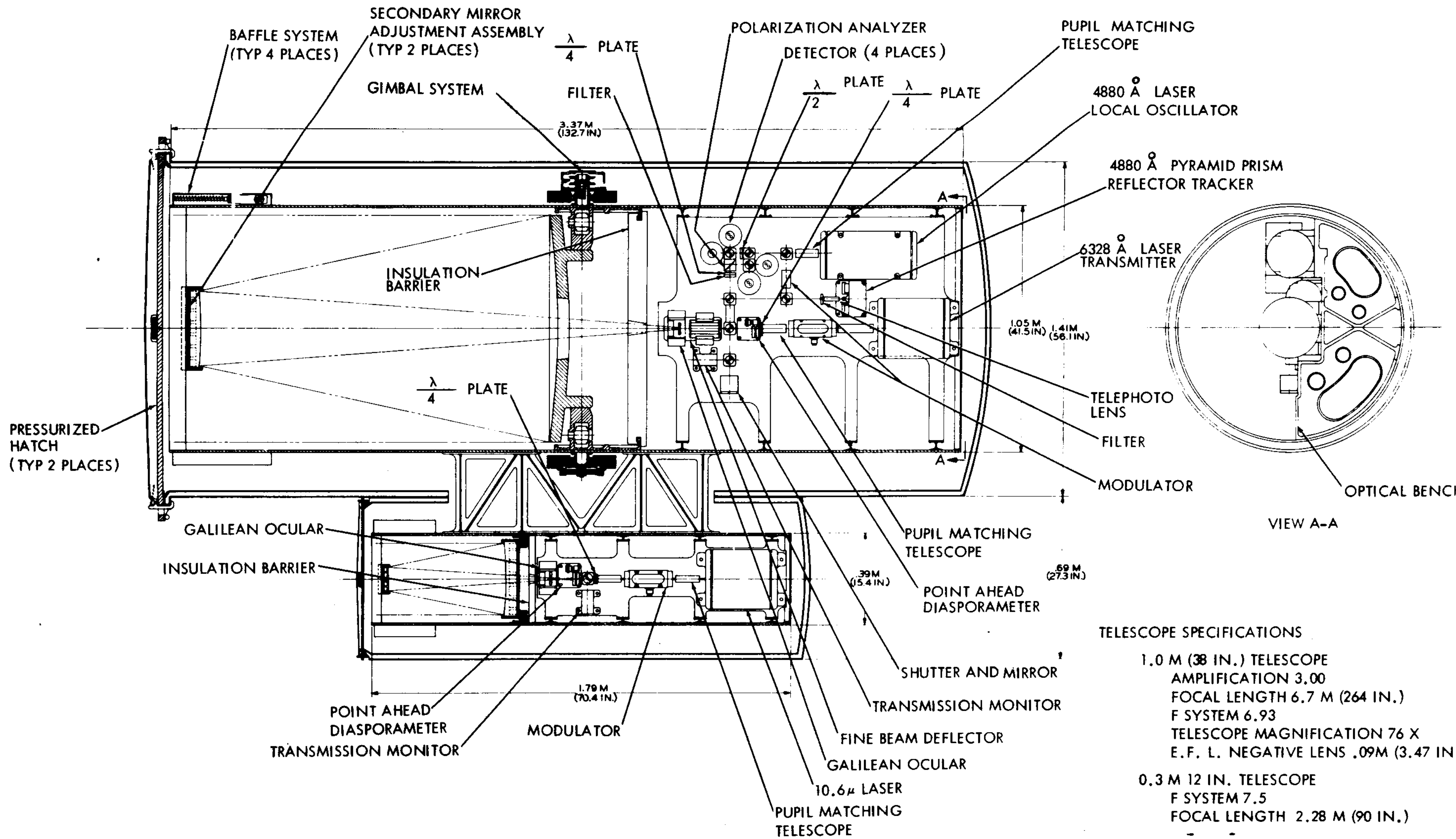


Figure 7. One Meter Telescope with Three-tenths Strapped Down Telescope

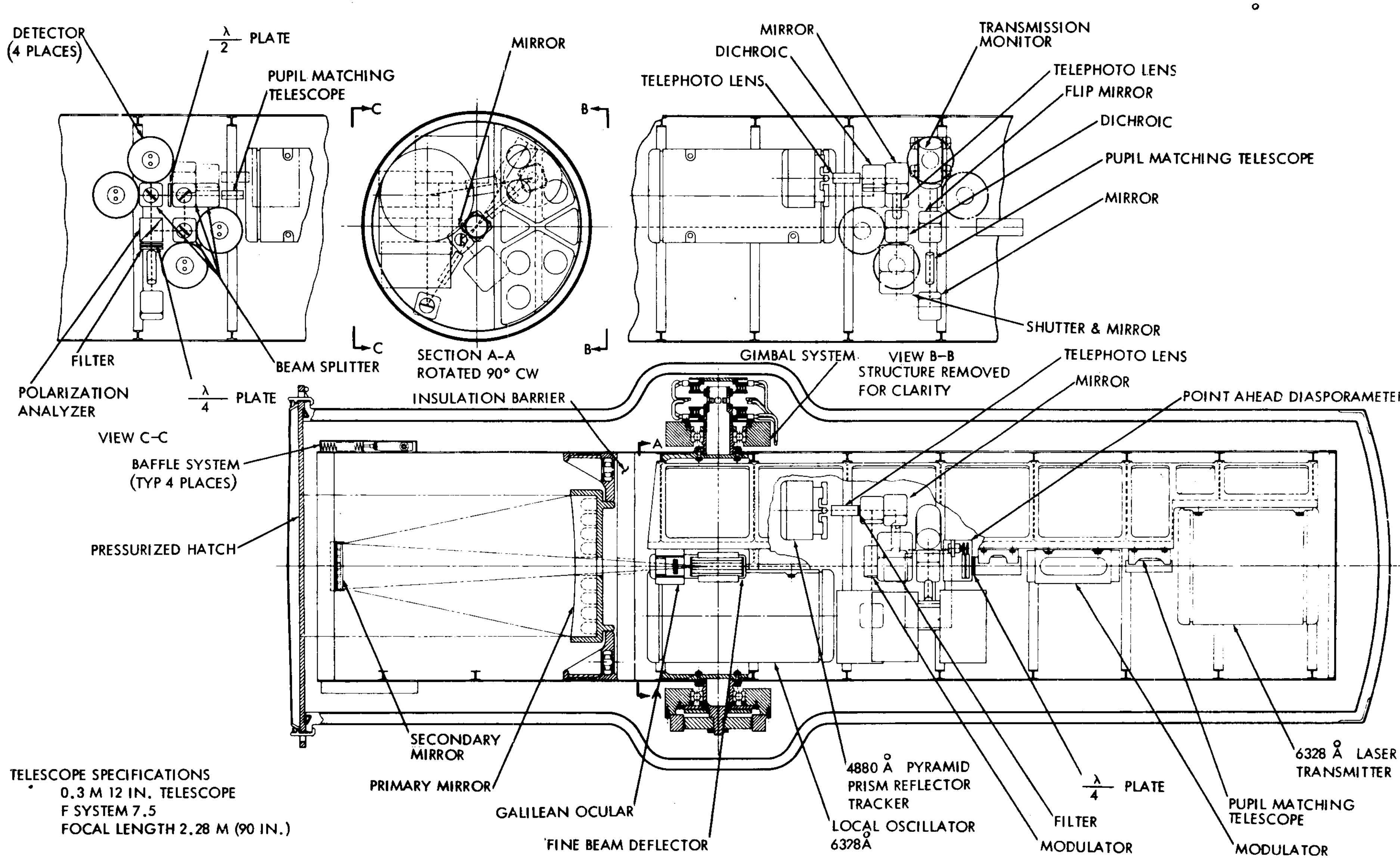


Figure 8. Three-tenths Meter Gimballed Telescope

a pointing capability commensurate with the beam divergence (e.g., 0.1 arc-second). Achieving this accuracy requires a precise reference from the ground station to the spacecraft. This reference is established by precise tracking of an upcoming laser beam. Such tracking is the subject of one experiment. It should be pointed out that this tracking is required to support the other experiments, thus no additional spacecraft equipment is required.

An important element of the communications experiements is to simulate, as nearly as is practical, communication conditions from deep space. For tests whose alternate objective is the development of operational techniques, it is important that the technology be exercised under realistic conditions since communication from the planets will require, among other things, the transfer of tracking from one ground station to another. The objective of one of the proposed experiements is to develop this capability. Another particularly difficult problem with a two-way communication link with deep space is the lead angle which must be incorporated into the transmitter beam. Caused by the relative velocities between the spacecraft and the ground station and the relatively long transit times, the lead angle requirement may typically be as great as 40 arc-seconds for a Mars flyby.

Two experiments of the optical propagation group are designed to explore important properties of the atmosphere in order to first test a technique for measuring phase variations as a function of time, with a highly monochromatic laser source and, second, to study phase and amplitude characteristics of the atmosphere as a transmission medium.

Telescope Technology Group

The second major group of proposed experiments is designed to advance space telescope technology. Figure 9 is a detailed experiment well concept which facilitates this group. The outstanding goal in space astronomy, recommended by the Space Science Board, is the 3-meter (120-inch) telescope. The telescope aperture, by virtue of its size, establishes its light gathering capability. The light gathering power of this telescope is such that if complemented with a very high resolution capability, i.e., to its diffraction limit, it will permit astronomical observations not heretofore possible.

However, telescope resolution, exclusive of the particular optical configuration, is affected by mirror and/or lens surface shape deviation and smoothness, optical system alignment, optical materials and coatings, and lens material homogeneity. The most formidable problem is that of maintaining primary mirror diffraction-limited quality. To do this requires sensible and precise techniques for determining the deviation of the mirror figure from its required shape and, if a deviation exists, suitable methods for correcting the mirror figure so that the undesired deviations are removed.

Further, a mirror may return to its figure over most of its surface but fail to completely return on the balance. An evaluation of this condition under a space condition would be the only way to ascertain that the ground test conditions were not the cause of the discrepancy from prediction. In addition, a study was made of various methods for simulation of a zero g environment on Earth. Each approach reviewed had serious drawbacks resulting in a need for space testing.

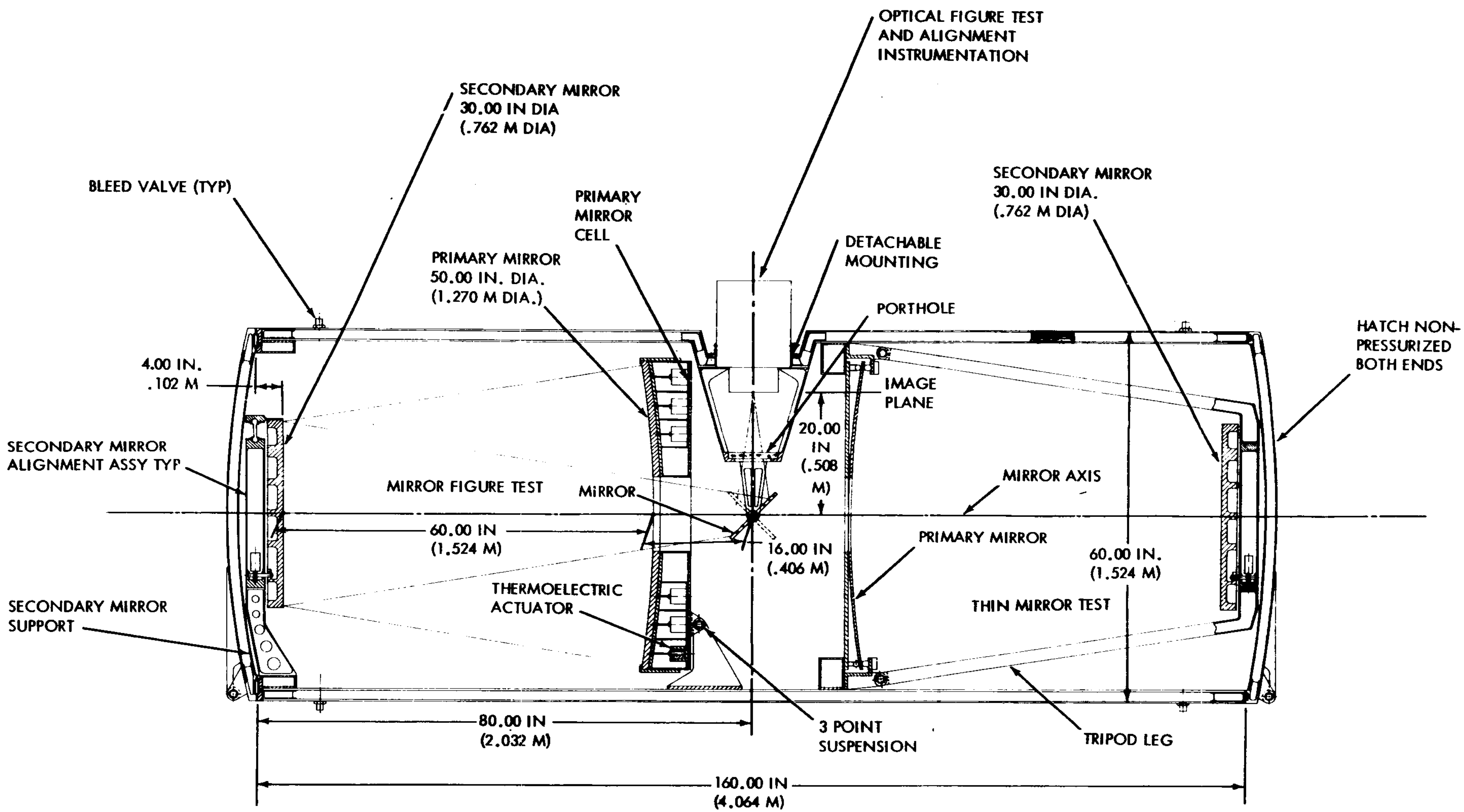


Figure 9. Primary Mirror Experiment Well

One possible solution to these problems is the use of a segmented primary mirror in the telescope. It is proposed as part of OTES to design, orbit, and test a small segmented telescope. The segmented telescope performance will be tested both by astronomical photography and by figure testing. A comparison of these results to ground-based results and predictions on the same telescopes will then allow a determination of the environmental affects on segmented mirror performance and, thus, of the merits of the concept. Another experiment proposes techniques for aleviating the figure control problem. By uniformly supporting a thin mirror during manufacture to eliminate the gravity-induced distortion, the mirror will tend to return to its proper figure in a low-g space environment. Figure 10 illustrates a possible future space operation including such a thin mirror concept.

Stellar Oriented Experiment Group

Experiments of this last major group are grouped together because, from an operation viewpoint, they share common subsystems. Figure 11 is a detailed telescope concept which facilitates this group.

The fine guidance experiment will serve the purpose of space development and testing of a highly stable star pointing system applicable to large telescopes (at least 100 inches). For this experiement the comparable performance is a pointing system stable to one one-hundredth of one second of arc when guiding on dim stars (+ 10 mag A0 star) against different background brightnesses.

The requisite testing and data gathering (of the proposed experiment) essential to the design of a large telescope fine guidance system include: evaluating the pointing stability as a function of star color temperature and magnitude; evaluating two types (at least) of fine sensors; testing reacquisition and fine guidance on consecutive half orbits (which is important in near earth orbit missions), and evaluating different fine beam deflectors.

The objective of the second experiment in this group is the development of isolation techniques. Precise stabilization of a space telescope, as discussed above, requires isolation from man-produced distrubances originating in the spacecraft. Several techniques, all of which are designed specifically to take advantage of zero g space conditions, are proposed for experimentation. One of these techniques, that of spring suspension, is depicted in figure 12.

The last experiment in the stellar oriented group is the stellar interferometer experiment. A stellar interferometer stationed in earth orbit, where beam vibration and atmospheric turbulence can be minimized, will be a valuable tool for increasing our knowledge of stellar and galactic dimensions, Cepheid characteristics, and mechanics of stellar systems.

The full effects of the space environment on the instrument cannot be obtained on Earth nor can they be adequately simulated in the presence of gravity. Data are also needed on the combination and transmission of the many disturbances as inputs to a beam analysis model. In short, comparison of beam concepts must be accomplished in space.

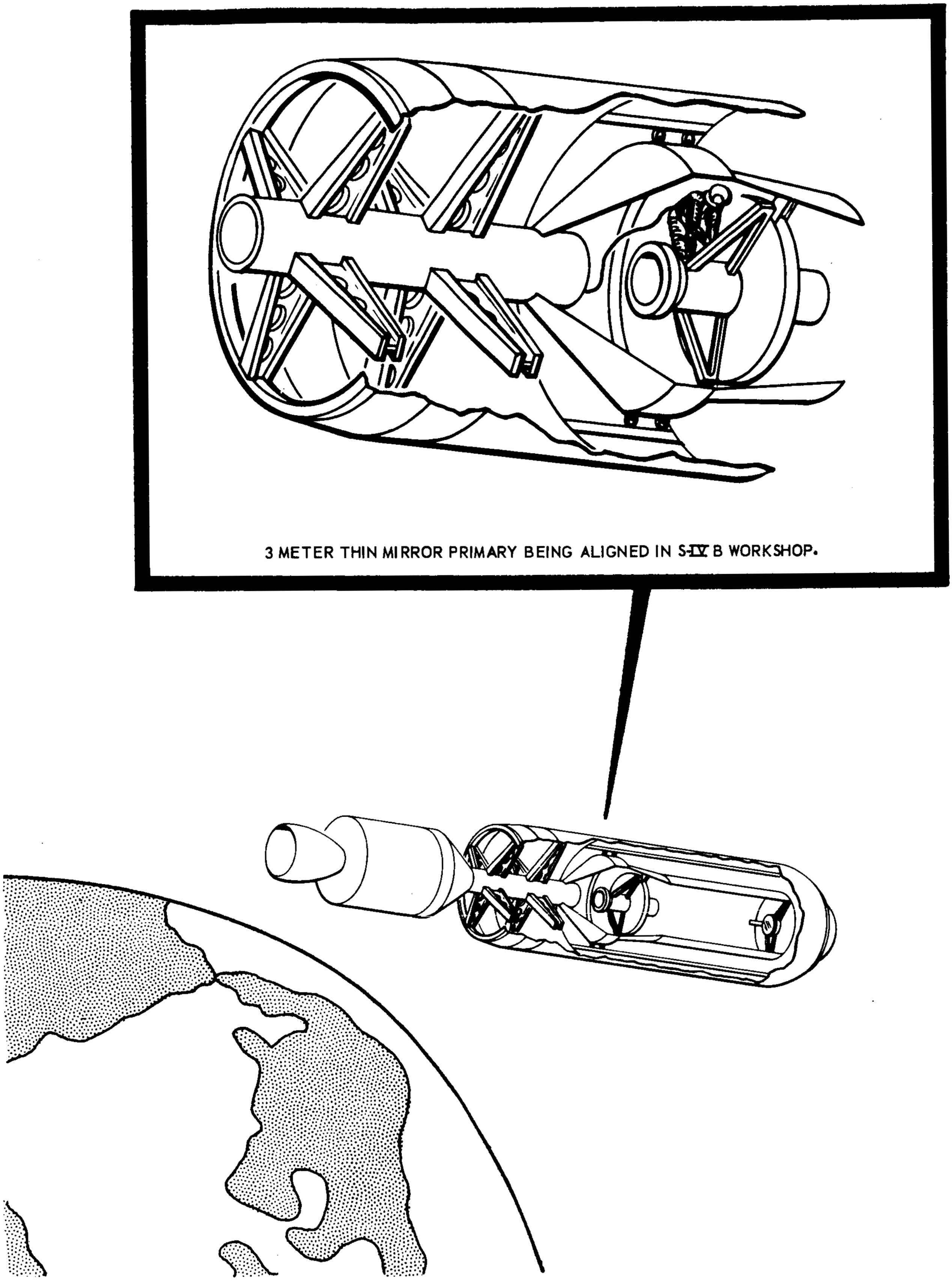


Figure 10. Thin Mirror Alignment in a Spaceborne Telescope

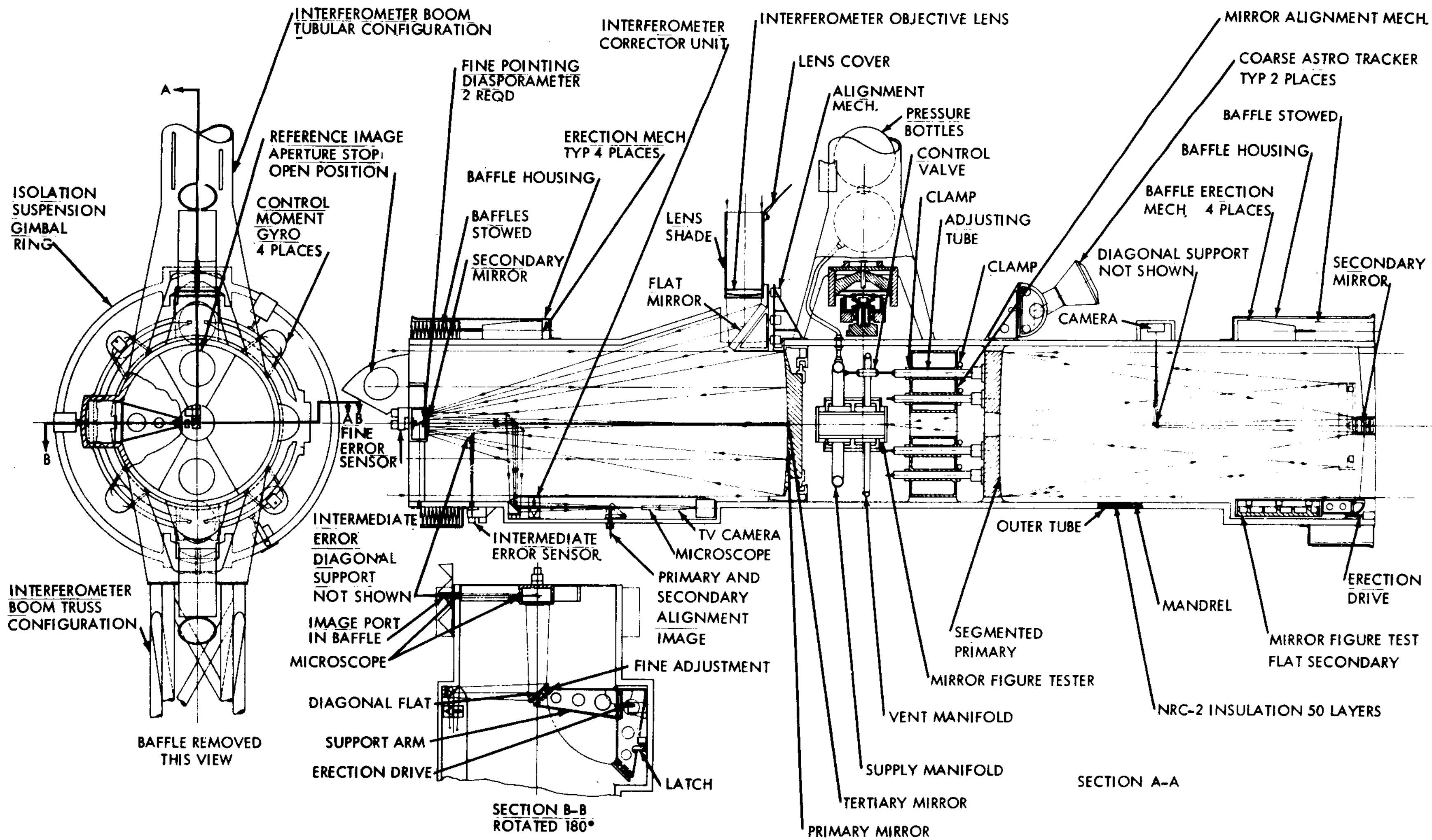


Figure 11. Six-tenths Meter Telescope

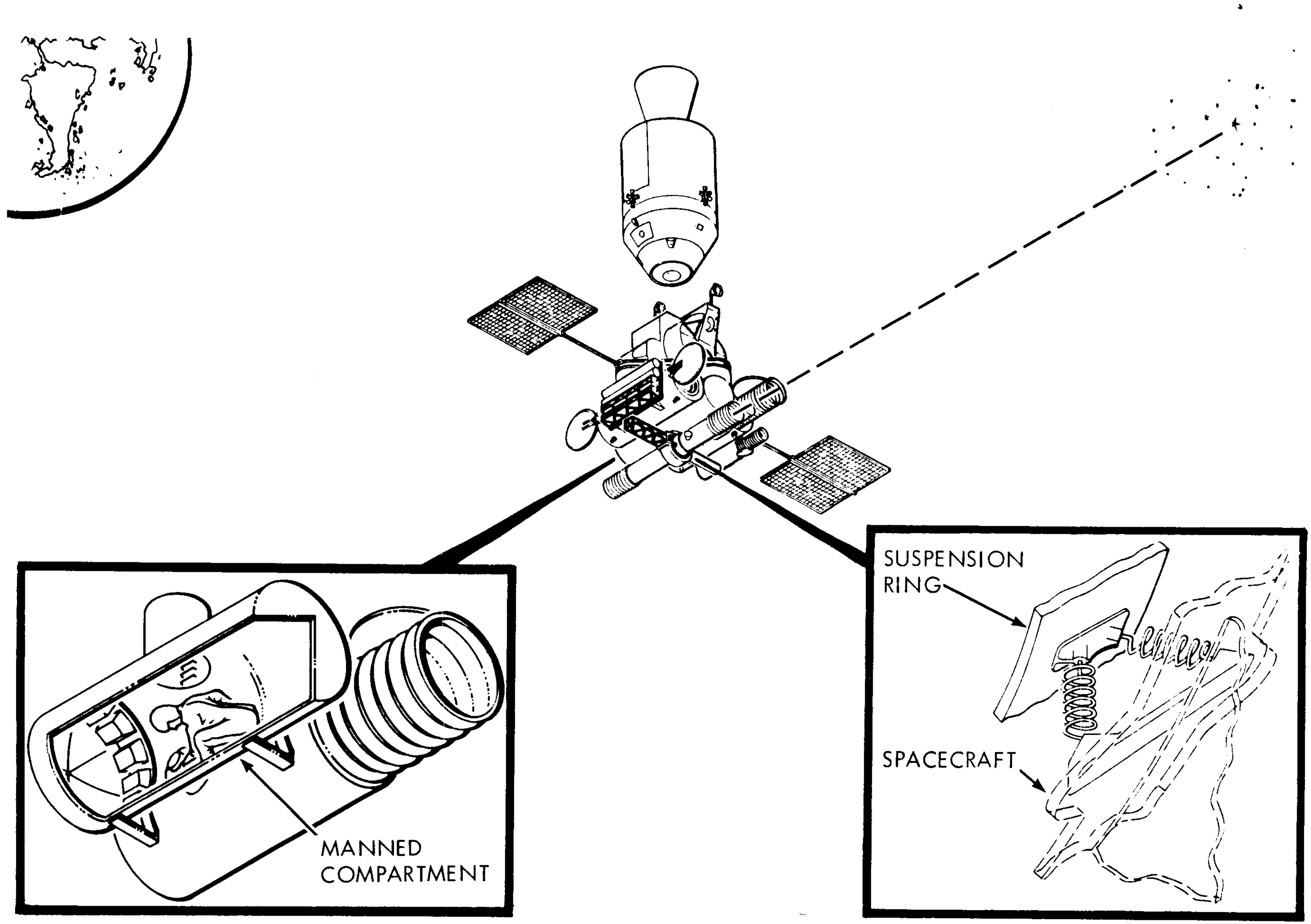


Figure 12. Operational Concept for the Stellar - Oriented Experiments - Isolation of Fine Guidance Telescope During Operation

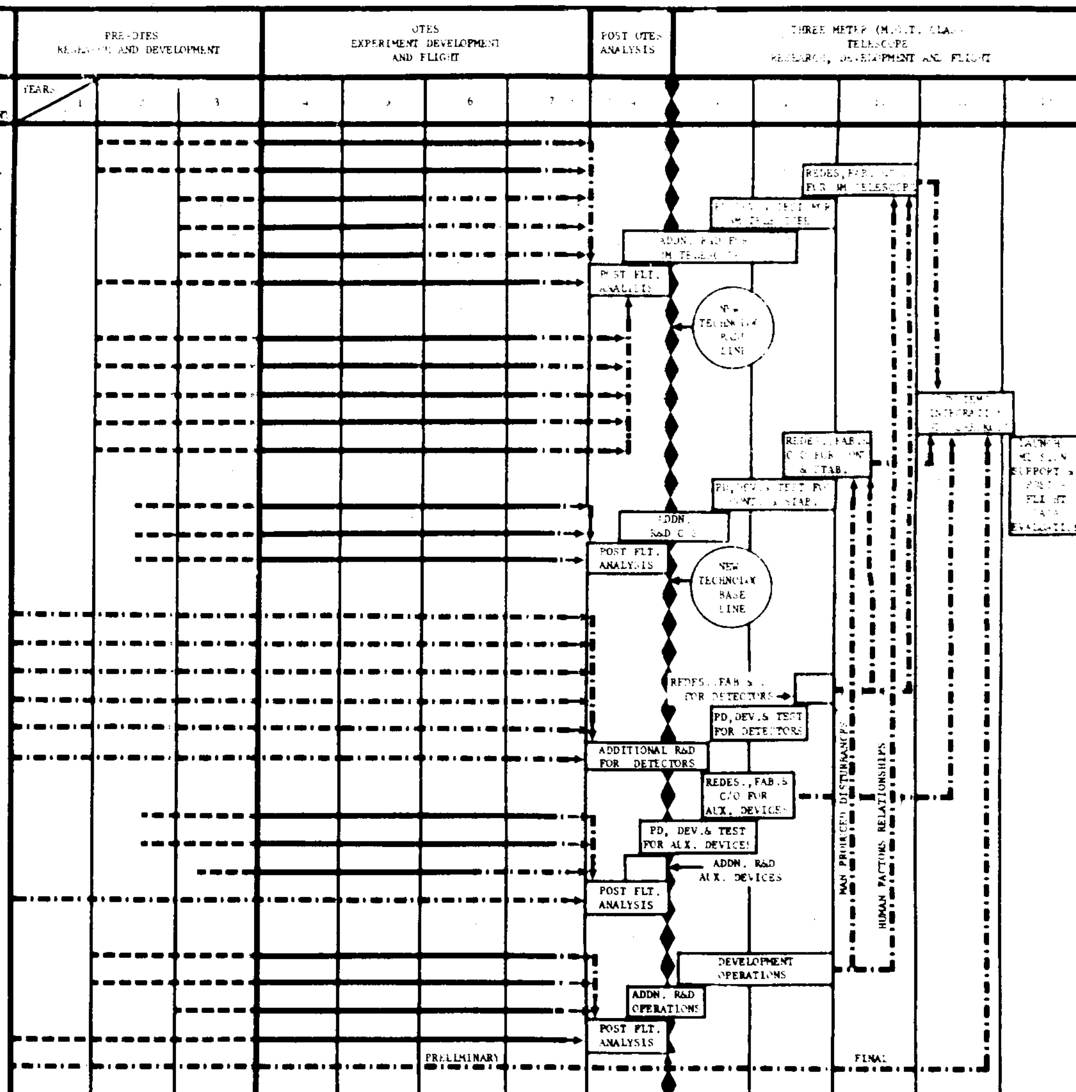
VI. DEVELOPMENT PLAN

One purpose of the OTAES study is to provide NASA with the comprehensive plan for the fulfillment of optical related space science technologies. As a guide, the OTAES technology development plan used two broad NASA goals: a large manned orbiting telescope and an interplanetary optical communications system. Most of the optical technology needs detailed in the first part of the OTAES study are satisfied by the achievement of these two goals.

A summary development plan was laid out for these two goals. Figures 13 and 14 are the plans for the manned orbiting telescope and interplanetary optical communication system, respectively. Specific OTAES experiments as well as prerequisite ground based testing to support these experiments appear in this schedule plan. Ground based testing not related to the OTAES experiments is identified by indicating specific technological areas in which such testing will be necessary. These tests, however, have not been time-phased.

It is evident by inspecting these plans that the OTAES flight experiments comprise a necessary step in the attainment of these planned goals. The technology advancements required to attain the long range goals are of such magnitude and complexity that a technology quantum jump approach does not appear feasible and that space experiments are a logical step to insure continuous technology advancement in all disciplines. Although the experiments can be designed to be flown singly and independently, much more will be gained by launching them in groups on a single vehicle or in closely timed launches.

TECHNOLOGY AREAS	RELATED EXPERIMENTS AND GROUND DEVELOPMENT: OTES EXPERIMENTS	OTES RELATED GROUND DEVELOPMENT	OTHER GROUND DEVELOPMENT
I. OPTICAL SUB-SYSTEM			
A. MATERIALS	10,11,15,16	G	REQUIRED
B. MIRROR FIGURE CONTROL	10,11,15	A,M	NOT REQD.
C. CONTAMINATION	16	G	REQUIRED
D. SURFACE DEGRADATION	16	[illegible]	NOT REQD.
E. MIRROR COATING	16	G	REQUIRED
F. THIN MIRROR	10,15,16	G	NOT REQD.
II. TELESCOPE STRUCTURE AND MECHANISMS			
A. PASSIVE THERMAL CONTROL	10,11,15	A,M,N	REQUIRED
B. SMALL DISPLACEMENT ACTUATORS	10,12,14,15	A,J,M,N	REQUIRED
C. ALIGNMENT SENSORS	10,11,15	A,J,M,N	REQUIRED
D. FOCUS SENSORS	10,11,15	A,J,M,N	REQUIRED
E. REMOTE ALIGNMENT PROCEDURES	10,11,15	A,J,M,N	REQUIRED
III. CONTROL/STABILIZATION			
A. TRACKING AND STABILIZATION	12,13		REQUIRED
B. ISOLATION AND GIMBALLING	12,13		REQUIRED
C. ACQUISITION	12	H	REQUIRED
IV. DETECTION AND CONDITIONING			
A. HIGH RESOLUTION DETECTORS		C,P	REQUIRED
B. DETECTORS SENSITIVE TO UV ONLY			REQUIRED
C. BROAD BAND PHOTO ELECTRIC DETECTORS		K	REQUIRED
D. HIGH DATA MAGNETIC TAPE STORAGE			REQUIRED
E. LOW LEVEL PHOTO ELECTRIC TUBE		C,K	REQUIRED
F. DRY DEVELOPMENT EMULSION		C	REQUIRED
V. AUXILIARY DEVICES			
A. VARIABLE DISPERSION SPECTROGRAPHS	12,13,16	F,J	REQUIRED
B. UV SPECTROGRAPH	12,13,16	F,J	REQUIRED
C. INTERFERENCE SPECTROMETERS	14		REQUIRED
D. BAFFLE SYSTEMS		E	REQUIRED
VI. OPERATIONS			
A. ERECTION AND CHANGE-OVER PROCEDURES	10,11,14,15	A	REQUIRED
B. LOGISTICS	10,11,14,15	C,E,G,N,	REQUIRED
C. OPERATING MODES	13	S	REQUIRED
D. LAUNCH ENVIRONMENT	ALL		REQUIRED
E. OBSERVATION PROGRAM AND PLAN	NONE	NONE	REQUIRED



NOTES: 1. SEE SECTION 16.0 FOR EXPERIMENT DEVELOPMENT DETAILS.

2. THIS FIGURE IDENTIFIES BUT DOES NOT SCHEDULE OTHER NEEDED GROUND DEVELOPMENT NOT SPECIFICALLY IN SUPPORT OF SPACE EXPERIMENTS.

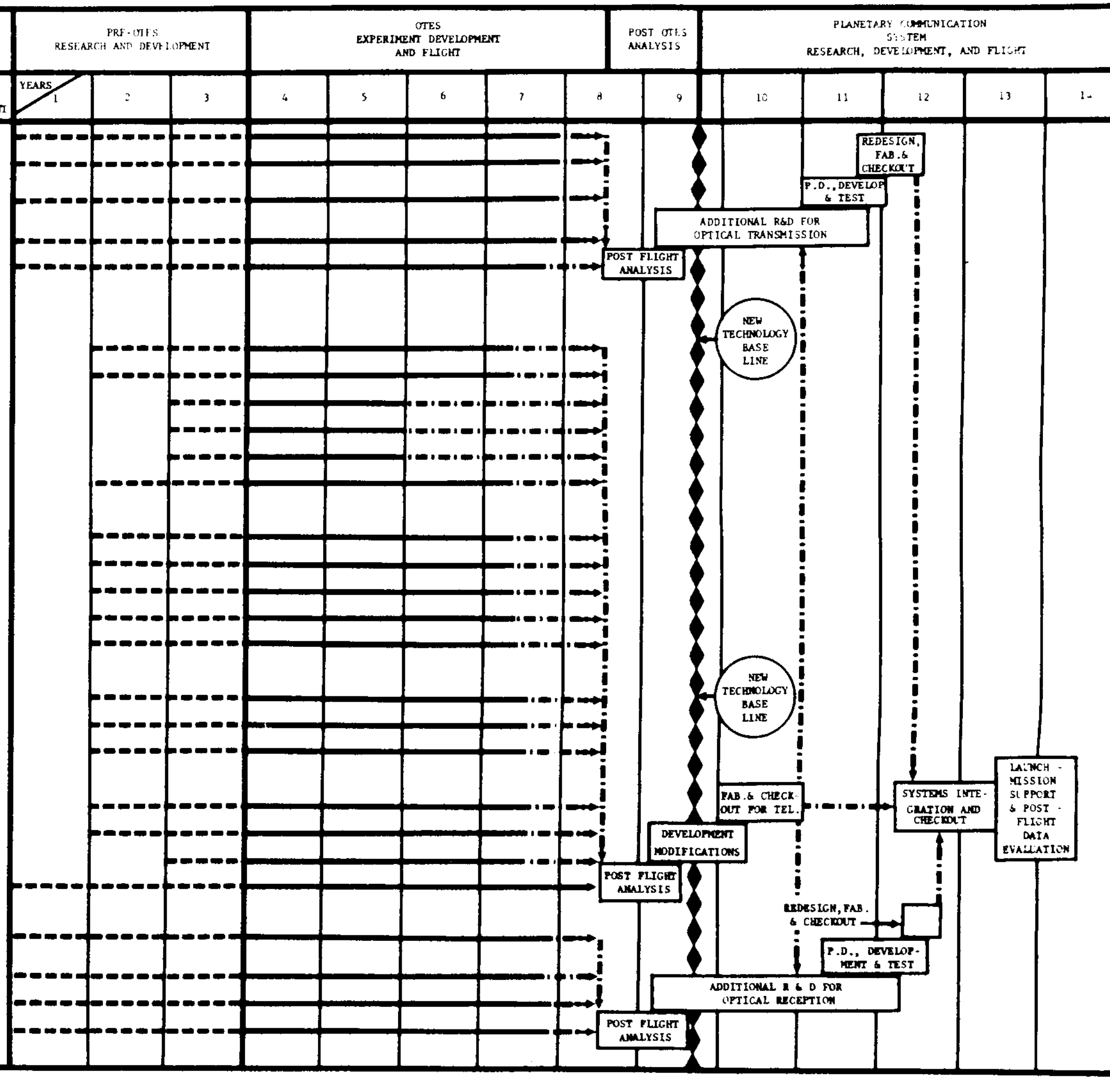
KEY

OTES EXPERIMENT DEVELOPMENT & FLIGHT
PRE-OTES RESEARCH & DEVELOPMENT
GROUND DEVELOPMENT & DELAY TIME

LONG RANGE ASTRONOMICAL TECHNOLOGY DEVELOPMENT MILESTONES

Figure 13

TECHNOLOGY AREAS	RELATED EXPERIMENTS AND GROUND DEVELOPMENT: OTES EXPERIMENTS	OTES RELATED GROUND DEVELOPMENT	OTHER GROUND DEVELOPMENT
I. OPTICAL TRANSMISSION			
A. PATH CHARACTERISTICS AND LINK DEGRADATION	1,2,3,4,5,8,9	B	REQUIRED
B. MEANS OF TRANSMISSION	1,2,3,4,5,6,7 8,9	B	REQUIRED
C. SPACE QUALIFIED SUPPORTING COMPONENTS	1,2,3,4,5,6,7 8,9		REQUIRED
D. OPTIMAL TRANSMITTING FREQUENCIES	1,2,3,4,8,9		REQUIRED
E. INFORMATION TRANSMISSION RAT	1,2,3,4		REQUIRED
II. SUPPORTING TELESCOPE TECHNOLOGY			
A. OPTICAL SUB-SYSTEMS			
1. MATERIALS	10,11,15	G	REQUIRED
2. MIRROR FIGURE CONTROL	10,11,15	A,M	NOT REQD.
3. CONTAMINATION		G	REQUIRED
4. SURFACE DEGRADATION		G	NOT REQD.
5. MIRROR COATING		G	REQUIRED
6. THIN MIRROR EVALUATION	10,15	G	NOT REQD.
B. TELESCOPE STRUCTURE & MECHANISMS			
1. PASSIVE THERMAL CONTROL	10,11,15	A,M,N	REQUIRED
2. SMALL DISPLACEMENT ACTUATORS	10,12,14,15	A,J,M,N	REQUIRED
3. ALIGNMENT SENSORS	10,11,15	A,J,M,N	REQUIRED
4. FOCUS SENSORS	10,11,15	A,J,M,N	REQUIRED
5. REMOTE ALIGNMENT PROCEDURES	10,11,15	A,J,M,N	REQUIRED
C. CONTROL AND STABILIZATION			
1. POINTING AND TRACKING	5,6,7	B,E,H	REQUIRED
2. POINT AHEAD	6		REQUIRED
3. ACQUISITION	5,7	B,H	REQUIRED
D. OPERATIONS			
1. ERECTION AND CHANGE-OVER PROCEDURES	10,11,14,15	A	REQUIRED
2. LOGISTICS	10,11,14,15	C,E,G,N	REQUIRED
3. OPERATING MODES	13	S	REQUIRED
4. LAUNCH ENVIRONMENT	ALL		REQUIRED
III. OPTICAL RECEPTION			
A. TYPE OF RECEIVER	1,2,3,4,5,6, 7,8,9	K,R	REQUIRED
B. MEANS OF DETECTION	1,2,3,4,6,9	K,R	REQUIRED
C. OPTIMAL RECEIVING FREQUENCY	1,2,3,4,8,9	K	REQUIRED
D. SIGNAL PROCESSING	1,2,3,4,6,7 8,9		REQUIRED



NOTES: 1. THIS FIGURE IDENTIFIES BUT DOES NOT SCHEDULE OTHER NEEDED GROUND DEVELOPMENT NOT SPECIFICALLY IN SUPPORT OF SPACE EXPERIMENTS.

KEY

- (solid line) OTES EXPERIMENT DEVELOPMENT AND FLIGHT
- (dashed line) PRE-OTES RESEARCH AND DEVELOPMENT
- (dash-dot line) GROUND EXPERIMENTS AND DELAY TIME

LONG RANGE OPTICAL PROPAGATION TECHNOLOGY DEVELOPMENT MILESTONES

Figure 14

GOVERNMENT FIELD PRINTING PLANT
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